Distribution of I-, S- and A-Type Granites in the Eastern United States

Ian Harper

GEOL 394

April 28th, 2020

Advisors: Philip Piccoli, Austin Gion

Abstract

The purpose of this study is to evaluate the distribution of I-, S-, and A-type granites in the eastern United States and from these results examining the age relationship of I-,S-, and A-type granites in the eastern United States. Chappell and White (1974) first developed the classification scheme of I- and S-type granites in the Lachlan Fold Belt in Australia. In that study, based primarily on composition and mineralogy, they interpreted granitic rocks to originate from igneous or sedimentary source rocks. The I-, and S-type granites described by Chappell and White (1974) have some distinctly different characteristics, one being that I-type granites are metalumious, whereas S-type granites are peraluminous. A-type granites were identified later by Loiselle and Wones (1979) and were described as being more alkaline than I- or S-type granites. In this study, maps of granitic bodies were constructed for rocks of the eastern United States. Published studies were used, along with diagnostic features, to determine if those rocks have I-, S- or A-type granite characteristics. Mapping of I-, S-, and A-type granites was performed on the GIS software ArcMap and maps were color coded based off which classification they fall under. Areas of the rocks have been calculated by using the United States Geological Survey (USGS) mapping databases. The null hypothesis for this study is that the proportion of S-type granites relative to I- and A-type granites does not change with respect to time in the eastern United States. The alternate hypothesis is that the proportion of S-type granites relative to I- and A-type granites does change with respect to time in the eastern United States. In total, 232 granite formations have been identified based on their mineralogy. Other formations have not been categorized due to a lack of appropriate readily available descriptions and those formations were labeled as being "unknowns". The ages of the granite formations have been compiled from the literature and those ages were determined by various techniques including, U-Pb, Rb-Sr, Sm-Nd, and in some instances K-Ar. The largest area of magmatism (and presumably volume) of the named formations, occurred at approximately 400 Ma, during the Acadian orogeny. The total area for the named granites in eastern United States are 42,481 km^2: 19,686 km^2 for I-type granites, 3,453 km^2 for S-type granites, 3,612 km^2 for A-type granites, and 15,637 km^2 for the unknown formations. F-, and t-tests were performed to determine if the ages of I-,S-, and A-type granites were statistically different. This study has determined that S-type granites in the eastern United States are younger than I-type granites at the 95% confidence lever but are not younger than A-type granites at the 95% confidence level. Results show that the area of I-type granites in the eastern United States is greater than S- and A-type granites. These results contrast with those found by Chappell and White (1974) for the Lachlan Fold Belt as they had a similar distribution of I-type to S-type granites with a minimal amount of A-type granites.

Table of Contents

Introduction and Background 4

Methods of Analysis 8

Presentation of Data/Analysis of Uncertainty 12

Discussion of results 22

Conclusions 23

Acknowledgments 24

Bibliography 25

Appendix 29

Introduction and Background

Granites are plutonic rocks that are defined as felsic igneous rocks that are formed by the crystallization of magma and form a major part of the continental crust. Granitic bodies come in different sizes and compositions. Plutons, by definition, have an area of exposure of less than 100 km^2 (Winter, 2009). Batholiths, on the other hand, may contain multiple plutons of similar age, and have an area that is greater than 100 km^2 (Winter, 2009). Granitic rocks consist mostly of quartz, alkali feldspar, and plagioclase. Minerals such as hornblende, muscovite, and biotite are also commonly a part of the mineralogy of a granite. The Streckeisen diagram (Figure 1), is used to name plutonic rocks and does so based on their mineralogy. The Streckeisen diagram (Figure 1) is used to name plutonic rocks and is based on their mineralogy. The "Q" in the diagram stands for quartz, the "A" in the diagram stands for alkali feldspar, and the "P" in the diagram stands for plagioclase. Granites will be referred to in two different ways in this study when discussing rocks: granites (s.s.-in the strict sense); rocks that fall in the granite field on the Streckeisen diagram, and granites (s.l.-in the general sense). Granites (s.l.) include rocks such as quartz diorite, granodiorites and tonalites which fall on the Streckeisen diagram outside of the granite (s.s.) field.

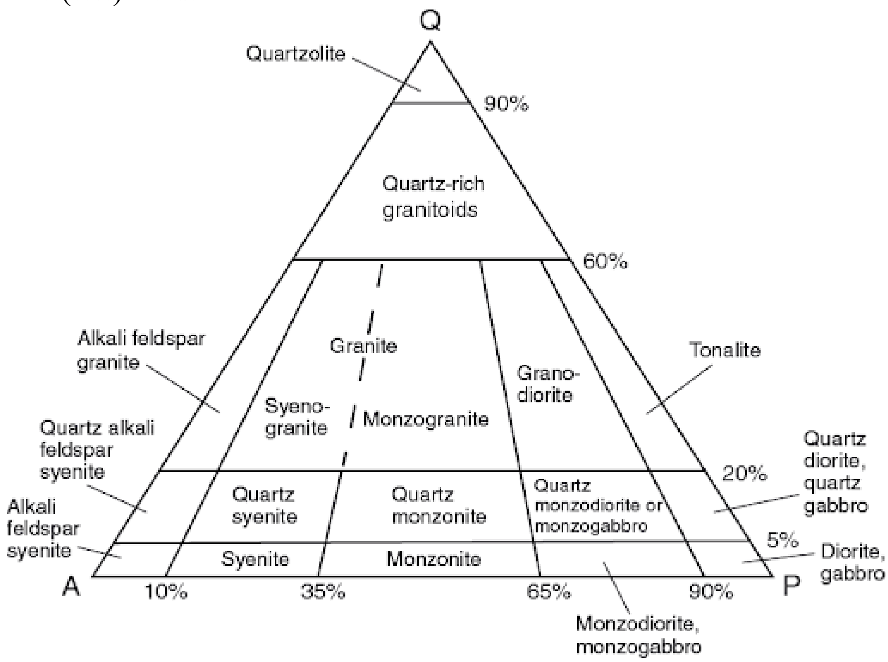

Figure 1: Streckeisen QAP diagram used to identify granites. Figure from Winter (2009).

Although granites are common, there have been disputes on how to best classify them. A common classification method that is used today is the alphabet genetic classification scheme including I-, S-, and A-type granites. I- and S-type granites are classified based on the inferred lithology of the protolith that melted to form them. I-type granites have an igneous source rock and S-type granites have sedimentary source rock. A-type granites are based more on composition and tectonic setting.

The classification method I-,S-, and A-type granites was first defined for rocks in Australia in the Lachlan fold belt in a paper titled "Two Contrasting Granite Types" (Chappell and White, 1974). Chappell and White (1974) discusses how I-, and S-type granites are classified based on the interpretation of their source material. I-type granites have an igneous rock as their source and are often referred to being metaluminous, while S-type granites have a sedimentary rock as their source and are referred as being peraluminous. S-type granites melted from a sedimentary source rock, whereas I-type granites are being melted from an igneous source rock. A-type granites are not based on their source rock and are classified based on their mineralogical composition and tectonic setting. A-type granites were first introduced by Loiselle and Wones (1979) and were described as anorogenic and mildly alkaline. In A-type granite source regions, the potassium and sodium oxide content of these rocks is high enough for alkaline minerals to form such as the sodic amphibole riebeckite. Chappell and White (1974) describe differences in these types of granites citing hornblende as being an identifying mineral for I-type granites and primary muscovite and cordierite being an identifying mineral for S-type granites. The mineralogy used to identify I-, S- and A-type granites is as follows can be found in Table 1.

Granite Type	**Mineralogy of Granite**
I-type granite	Hornblende, titanite, magnetite, calcium-rich clinopyroxenes, spessartine-rich garnet
S-type granite	Al-rich biotite, cordierite, sillimanite, andalusite, muscovite, ilmenite, almandine-rich garnet
A-type granite	Annite, Al-rich biotite, olivine, aegirine (sodium-rich clinopyroxene), arfvedsonite, riebeckite.

Table 1: Mineralogy used to determine I-, S-, and A-type granites. Chappell and White (1983), Whitey (1988), Whalen (1987).

The difference in mineralogy between I-, and S-type granites has to do with the melting environment of their protolith rock. Whitney (1988) discusses how S-type granites are formed from the dehydration melting of sandstone and shale that contained muscovite and biotite, and that at moderate pressures and high temperatures cordierite becomes a product of this melting. However, at lower pressures and moderate high temperatures, cordierite does not form. I-type granites are discussed as forming from melting reactions from magmatic rocks containing quartz, feldspars and notable amounts of biotite and hornblende. Some granites that form from pre-existing rocks that contain muscovite may have the accessory minerals sillimanite, ilmenite, andalusite, and garnet which would align with more of an S-type granite protolith. Granites that form from the pre-existing rocks that contain hornblende may have accessory minerals such as pyroxene, magnetite and sphene, which may align with a composition of an I-type granite (Whitney, 1988). Granites that form from preexisting rocks that contain biotite may have accessory minerals such as garnet, sillimanite, cordierite, ilmenite and pyroxene which would align with a composition of an S-type granite (Whitney, 1988).

Chappell, (1984) describe how different I- and S-type granites in the Lachlan Fold Belt were formed. The granite melts of S-type granites usually occur as intrusive bodies and are formed around low-grade metamorphic rocks. S-type granites from the Lachlan fold show that some granite formations have an exclusively sedimentary source and had no mantle or oceanic crust components such as the Young batholith, and others have igneous source material such as the Gabo Suite. The I-type granites have a wider range of composition than the S-type granites. I-type granites are usually of crustal origin and are created by magmas at lower pressures. Chappell (1984) concludes that S-type granites have a more heterogeneous source rock than I-type granites. I-type granites have a more homogenous source rock and are thought to be derived from deeper levels than S-type granites. I-type granites are infra-crustal and are produced by the melting of the crust during underplating, whereas S-type are supracrustal and are generating by melting of material originally deposited on the crust (Chappell 1984).

Chappell and White (1983) analyzed the distribution of I-, S-, and A-type granites in the Lachlan Fold Belt in Australia. The peraluminous S-type granites in this region are described as having greywacke and shale protoliths and their mineralogy includes biotite, cordierite, garnet and orthopyroxene and they are peraluminous. The peraluminous-metaluminous I-types granites have a mantle derived source, and their mineralogy includes biotite, hornblende, and accessory magnetite and ilmenite. The A-type granites have iron-rich biotite as their main mafic mineral and have accessory minerals including arfvedsonite, and riebeckite. Whalen (1987) also notes the presence of aegirine and olivine in some A-type granites. The A-type granites are distinctively different chemically from I- and S-type granites as they have elevated concentrations Ga, Nb, Sn and Zr, and are peralkaline. Table 2 shows examples of batholiths in the Lachlan Fold Belt in Australia which contain both I-, S-, and A-type granites

Batholith Name	**I-type**	**S-type**	**A-type**
Bathurst (#2)	100%	0%	0%
Young (#18)	1%	99%	0%
Gabo (#6)	3%	0%	97%
TOTAL	52%	47%	1%

Table 2: Modified table from Chappell and Simpson (1983)

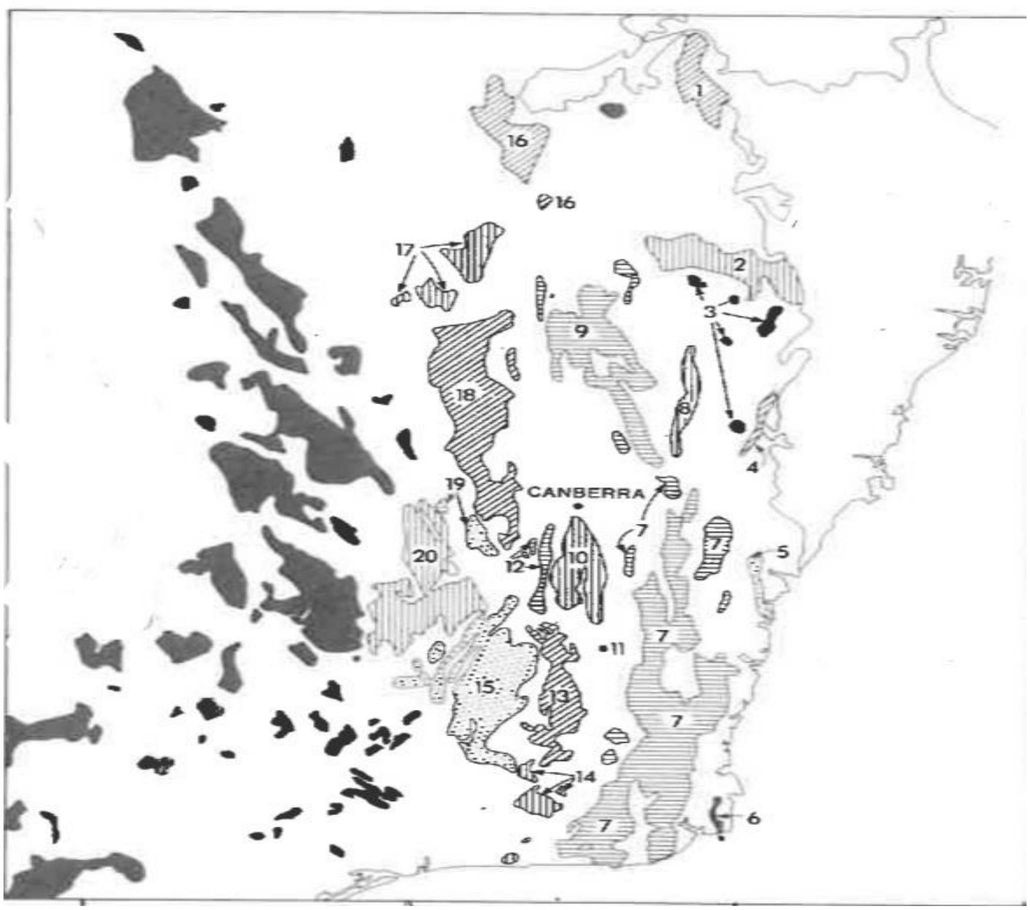

Figure 2:Lachlan Fold Belt Granite Distribution. Image modified from: Chappell, and White (1983)

The distribution of I-, S-, and A-type granites in the Lachlan Fold Belt in Australia are shown in Figure 5. Chappell and White (1983) determined that in this region there are roughly an equal amount of I-type to S-type granites with only a small percentage being A-type granites (examples are given in figure 4).

Barton et al. (1988) discuss granite magmatism (Figure 3) on the west coast of the United States and the role it plays in the extensive contact metamorphism it produced. Changes in magmatic flux are often associated with variations in plate motion. Variations in magmatic flux can result in plutons of different compositions. Barton et al. (1988) found that magmatism was concentrated during the Cretaceous, Triassic, and Jurassic time periods (Figure 3). Early plutonism is alkalic and less siliceous, and subsequent plutonism is usually subaluminous, while later plutonism is more peraluminous. subaluminous meaning that the molar proportion of aluminum oxide is lower than the combination of sodium oxide, calcium oxide, and potassium oxide. Peraluminous meaning that the molar proportion of aluminum oxide is higher than the combination of sodium oxide, calcium oxide, and potassium oxide. The first pulses of Mesozoic magmatism occur in a continuous band along the western United States and were mostly felsic granitoids. Changes in magmatic fluxes in this study will be related to major orogenic events on the eastern margin of the United States.

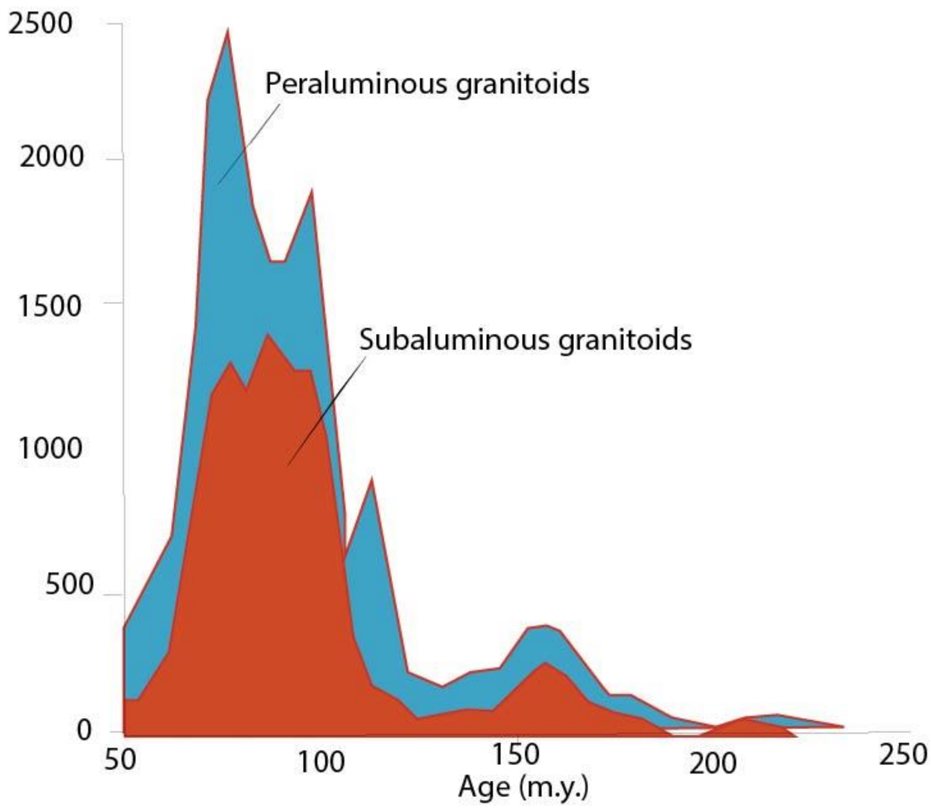

Figure 3:Plot of age versus area of exposure of granitic rocks of the western United States. Figure demonstrates the episodic nature of the magmatism. Reference: Modified from Barton. (1988).

Methods of Analysis

I-, S-, and A-type granites have been classified in the eastern United States covering as far south as Alabama and Georgia and as far north as Maine. I-,S- and A-type granites have been categorized based off their mineralogy (seen in table 1). The spatial and temporal distribution of the granites has been determined by calculating the area of the exposed portion of these granitic formations, in conjunction with compilation of the ages from the literature. By classifying I-, S-, and A-type granites in eastern North America, the relationships between the type of granite and the age of a granite can be determined. This study will specifically determine if there is a relationship among I- , S-, and A-type granites and their age.

-First null Hypothesis: The proportion of S-type granites relative to I-type granites does not change with respect to time in the eastern United States.

-First alternate Hypothesis: The proportion of S-type granites relative to I-type granites does change with respect to time in the eastern United States.

-Second null Hypothesis: The proportion of S-type granites relative to A-type granites does not change with respect to time in the eastern United States. .

-Second alternate Hypothesis: The proportion of S-type granites relative to A-type granites does change with respect to time in the eastern United States.

Given that sedimentary rocks are made from the products of weathering processes of pre-existing rocks, and previous studies have come to the conclusion that S-type granites are of supracrustal origin, rather than infra-crustal origin it is expected that S-type granites in North America will also have younger granite formations than I- and A-type granites. If results show that there is younger age of S-type granites with respect to I- and A-type granites, it can be inferred that areas that are more sediment rich, will produce more S-type granites.

Research was conducted using shape and KMZ files from the USGS. The shape files are the GIS files used to display granites in map view Those files contain spatial information on rocks reported on state maps. The files can be found at: https://mrdata.usgs.gov/geology/state/. These Geographic Information System files (or GIS files) are then uploaded and displayed using the GIS software ArcMap. ArcMap allows the user to interact with, manage, and display information in a map format. The first step after the files are loaded into ArcMap is to select the states of interest. These states were selected if they had outcrops of plutonic rocks, and included Alabama, Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont and Virginia (Figure 4).

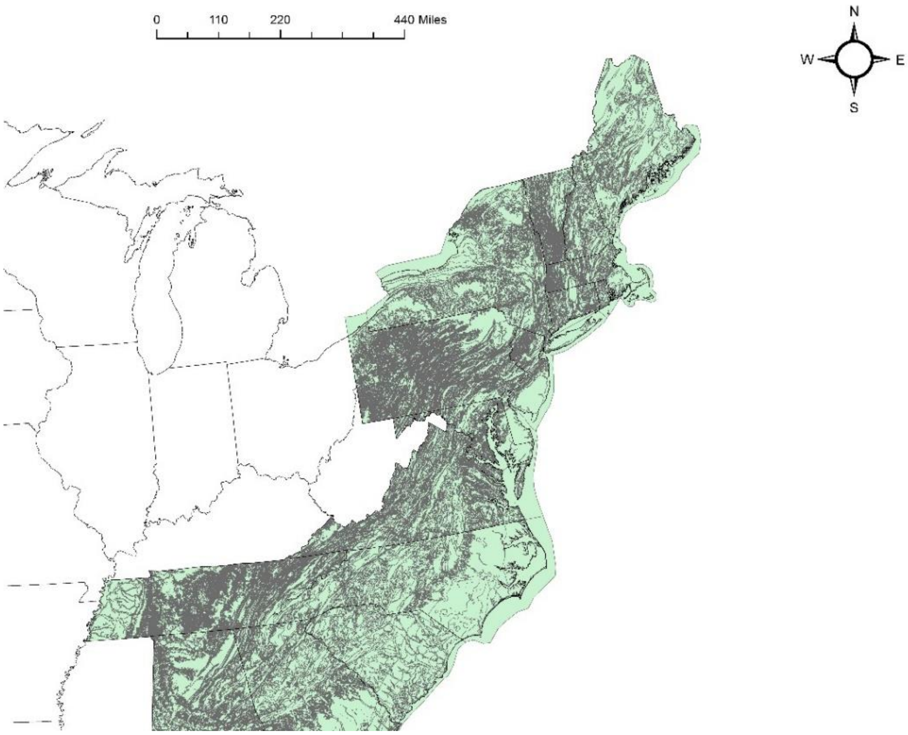

Figure 4: Formations on the eastern United States highlighted

An attribute table in ArcMap displays the names, and areas of the granite formations that have been selected. Rock types were selected in consultation with a Streickheisen diagram to highlight the granite formations from the shape and KMZ files mentioned previously. When granites have been selected in the GIS software ArcMap they are highlighted in map view which can be seen in Figure 5.

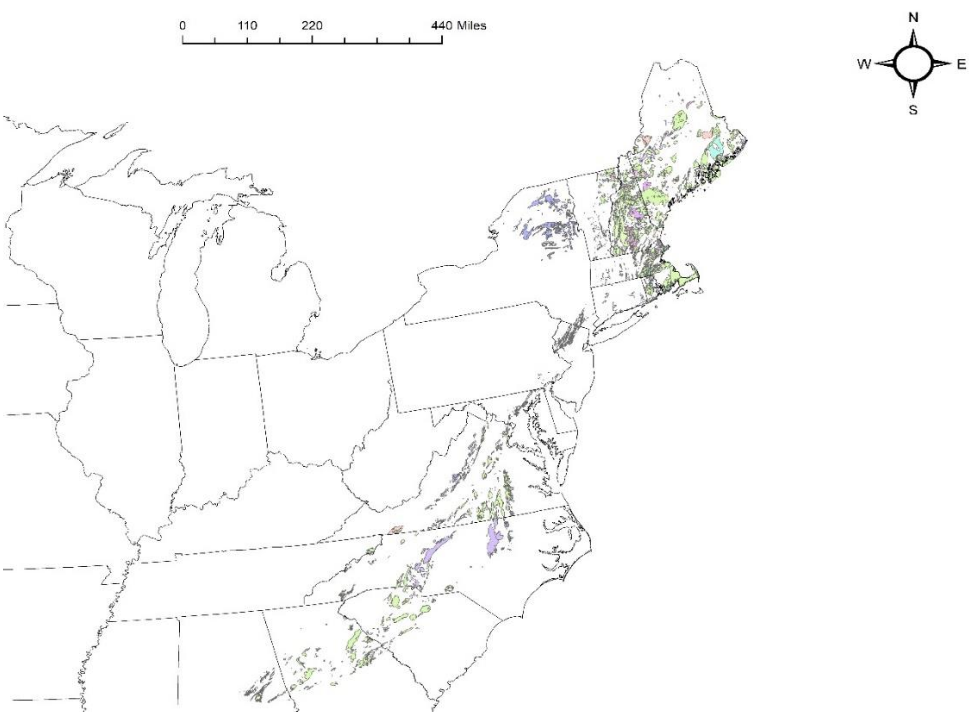

Figure 5: Example of highlighted plutonic formations in the eastern United States. Different colors represent different rock-types

The rock types that have been selected to be included in this study are: alaskite, alkali-feldspar-granite, alkali feldspar syenite, alkali-granite, anorthosite, aplite, charnockite, diorite, gabbro, gabbroic, granite, granitic, granodiorite, hornblendite, leucocratic granitic, monzodiorite, monzogranite, monzonite, pegmatite, quartz-alkali-feldspar-syenite, quartz diorite, quartz monzonite, quartz-syenite, tonalite, trondhjemite. The rock types identified for inclusion have been selected based primarily off the Streckeisen diagram (Figure 1). The rock types that were selected which do not appear on the Streckeisen diagram are older terms (e.g leucocratic granitic) that may be used on a state by state basis or rocks previously described associated with I-, S- and A-type granite systems. Selecting these rock types in ArcMap allows for the generation of a compilation of state maps containing only the rock type of interest (Figure 4). The names and areas of these formations are then transferred to Excel for data processing. This process must be done on a state to state basis as there may be multiple rock names for a single geometric shape displayed in ArcMap. The first step in data processing is to determine the granite type by using the mineralogy of the granites which was defined based on the literature (Table 1). If there is not enough information about the mineralogy to classify the formation as either an I-, S-, or A-type granite, it is classified as an unknown. Also formations that do not have a distinct name such as “biotite granite” cannot be researched as the term is too general to find specific information on. Lastly, many formations in Virginia have muscovite as a part of their mineralogy, but for muscovite to be an identifying characteristic for S-type granites, it must be primary and not secondary. If it is not explicitly stated in the literature that the muscovite is primary or secondary and no other identifying characteristic are found, the rocks are therefore classified as unknowns.

Some information was acquired from state geologic maps, but that information was sometimes incomplete. The shape and KMZ files contain spatial information, ArcMap is used to calculate the area of granite formations using the information from the shape and KMZ files.

The following flow chart gives an overview of each step in the research process:

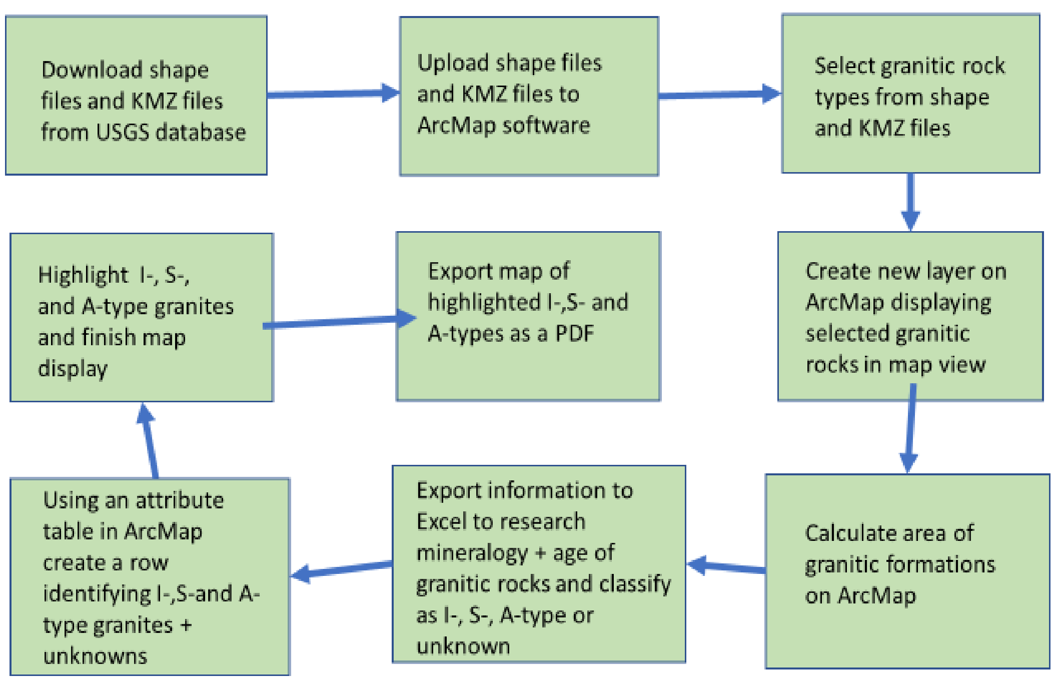

Figure 6: Flow chart of the research proces

After classifying the granite formations as I-, S- or A-type and calculating the exposed area, the literature was then searched to determine if appropriate age information exists for the rocks. Ages for many of the granites were found on state maps in the archives of the USGS database. The majority of the ages for the granite formations classified were found from the literature using U-Pb and Rb-Sr dating techniques and ages where U-Pb and Rb-Sr were not available for K-Ar techniques were used. U-Pb and Rb-Sr dating techniques are preferred over K-Ar and Sm-Nd techniques. One reason being that K-Ar techniques can be inaccurate when dating formations due the ease of resetting it's the K-Ar clock (loss of Ar) and there the age. U-Pb dating is the most accurate dating technique because zircons are less likely to be disturbed by geological events. After the process of determining the best age in the literature, the information is incorporated into the database along with the exposure area.

Presentation of Data and Analysis of Uncertainty
I-type Granites

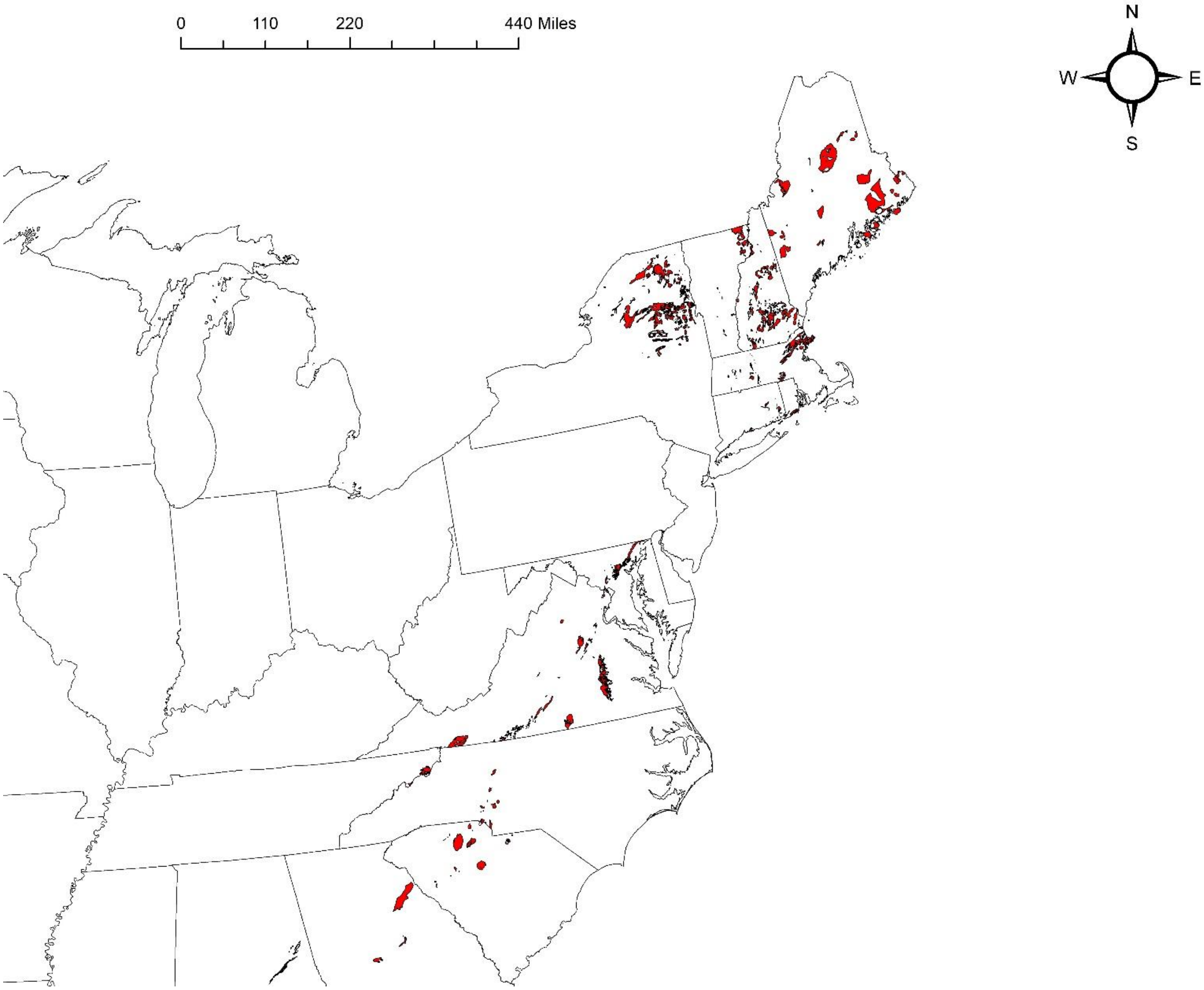

Figure 7: Area of I-type granites highlighted in red.

S-type Granites

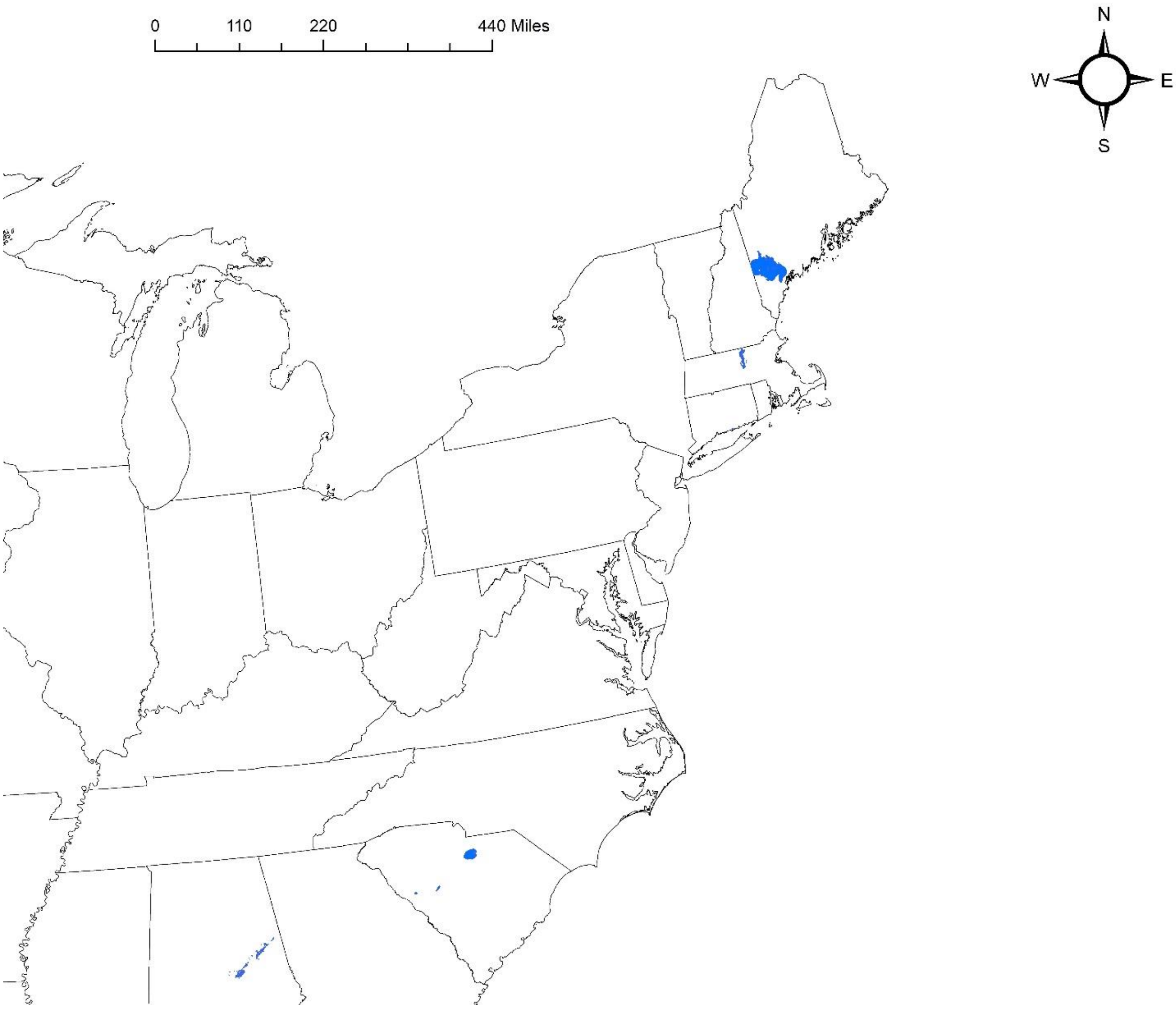

Figure 8: Area of S-type granites highlighted in blue

A-type Granites

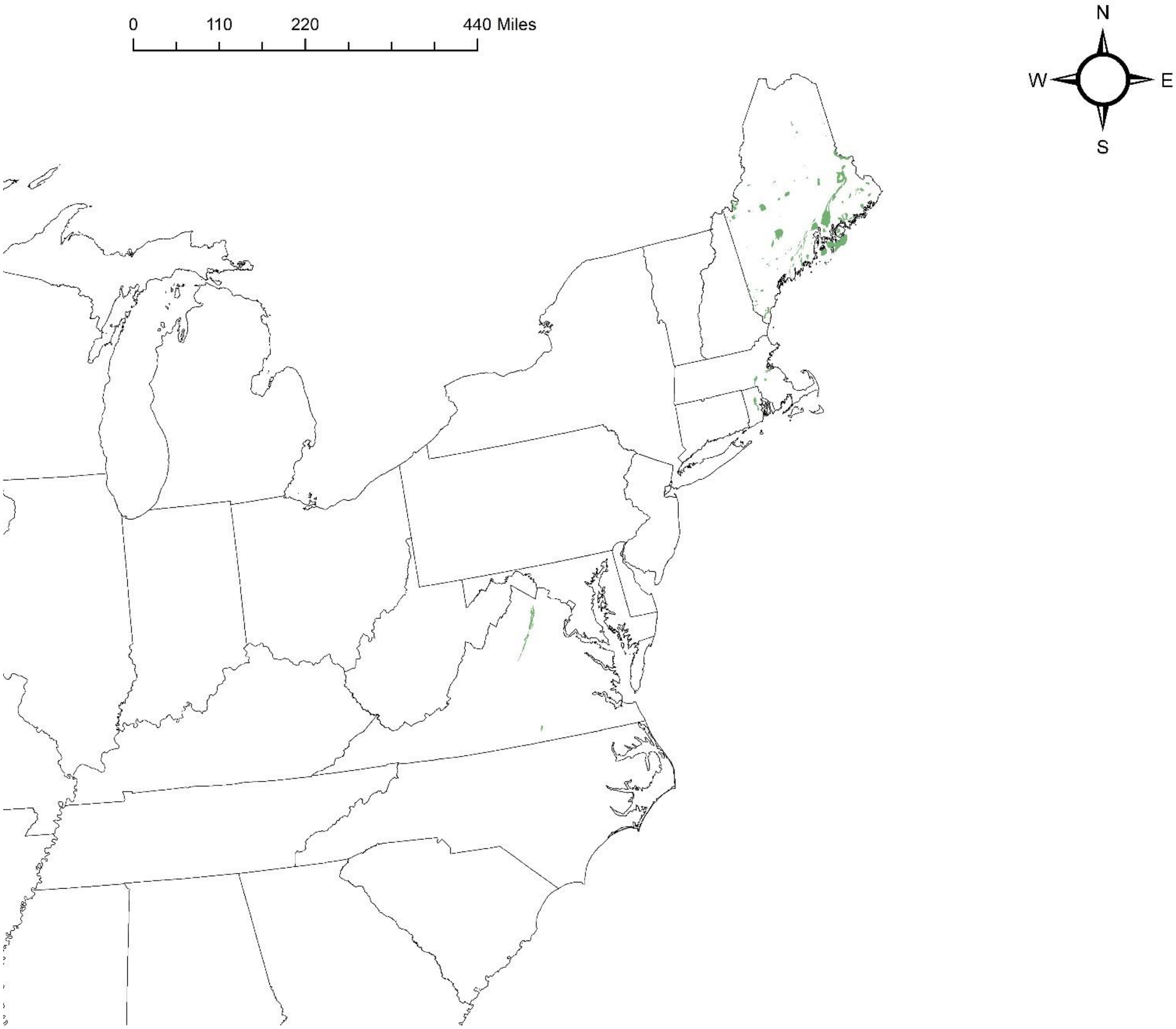

Figure 9: Area of A-type granites highlighted in green

.

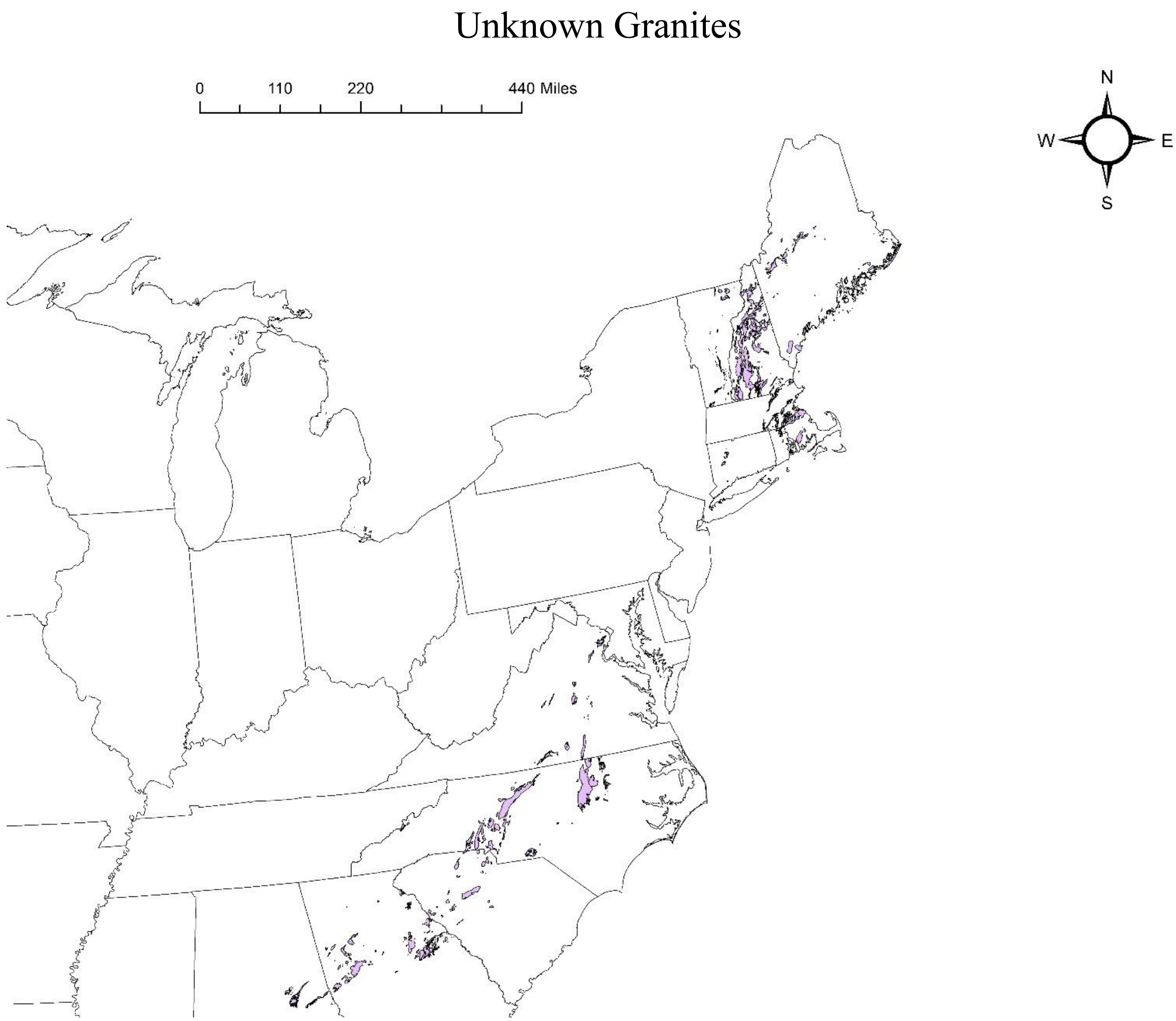

Figure 10: The area formations that did not have descriptions which enable the I-,S- or A-type classification are highlighted in purple

Formations That Were Not Researched

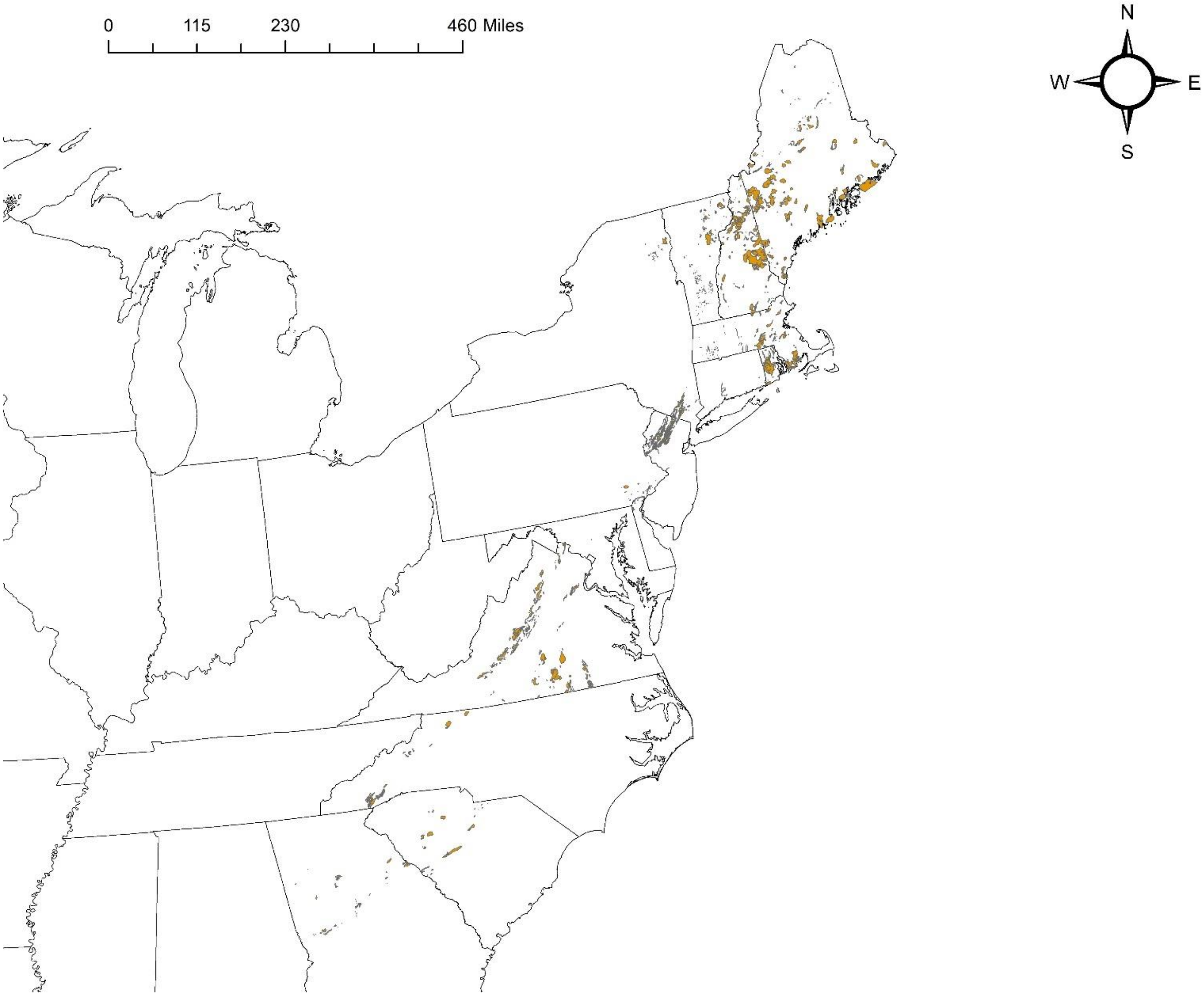

Figure 11: Area of the plutons that are either smaller than 100 km² or there were not names associated with the formation making it difficult to find any information on.

Eastern United States I-, S-, A-type granites

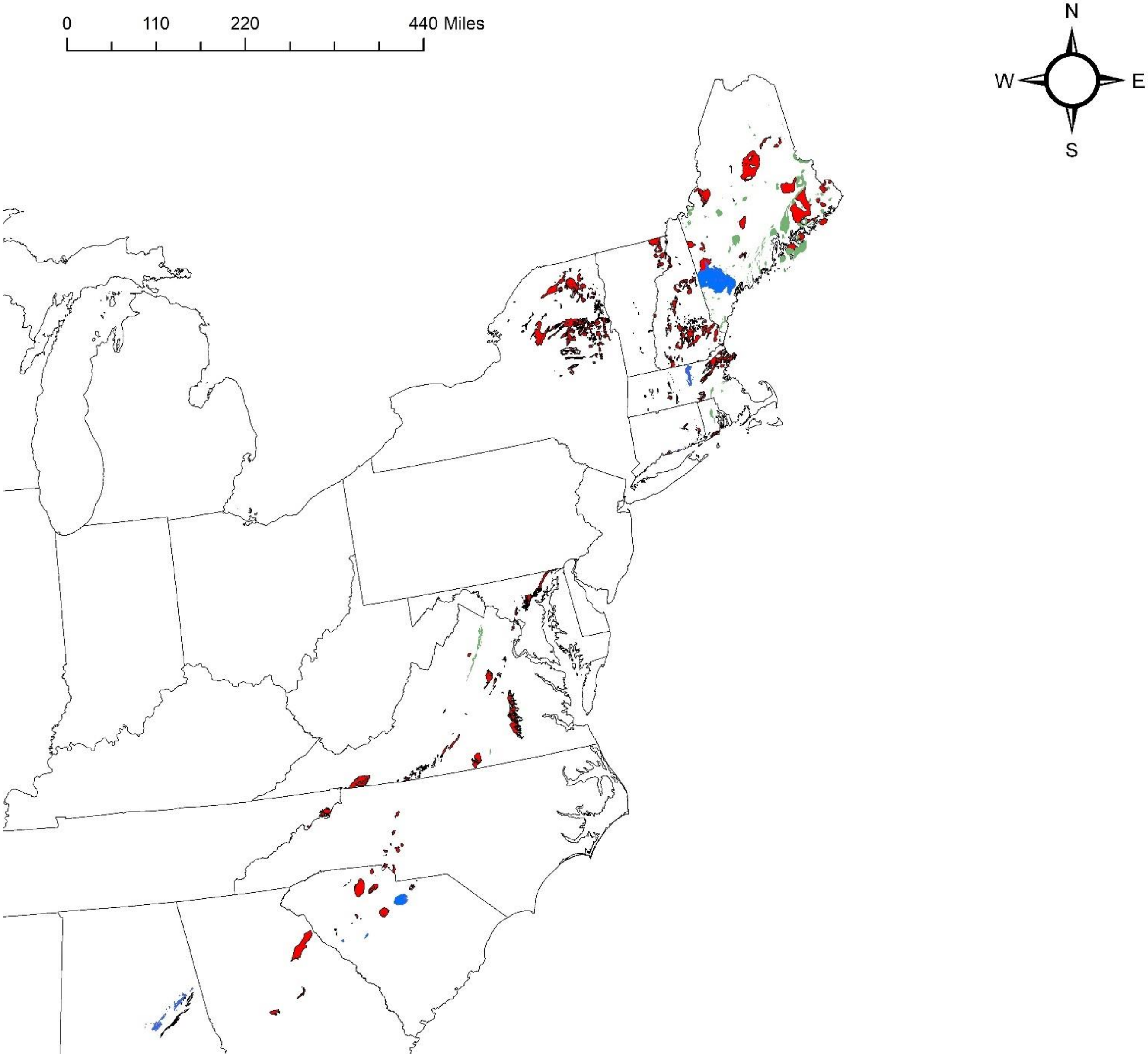

Figure 12: Map of the eastern United States displaying I-, S-, and A-type granites red being I-type, blue being S-type and green being A-type.

I type granites highlighted in red are the most abundant type of granite found in the eastern United States (Figure 7). Compared to S-type and A-type granites, I-type granites cover approximately 73.5% of the total area of plutonic rocks in the eastern United States which is approximately 19,686 km^2. S-type granites highlighted in blue are the least abundant type of granite in the eastern United States and they make up roughly 13% of the I-, S-, and A-type granites researched (Figure 8). S-type granites have an area of exposure of approximately 3,400 km^2. S-type granites make up the least amount of area and have substantially less plutons than I-type granites. Small bodies of S-type granites can be seen in the states South Carolina, Alabama, Massachusetts, and Maine.

A-type granites highlighted in green make up roughly 13.5% of the area of granites in the eastern United States (Figure 9) and take up an area of roughly 3600 km^2. Many of the formations identified were in Maine. Small bodies of A-type granites can also be found in Virginia in the Robertson River Igneous Suite, and in Massachusetts and Rhode Island. Unknown granites highlighted in purple (Figure 10) are formations that do not have the identifying minerals that were listed previously to categorize them as I-S-, or A-type granites. They make up roughly 36% of the total area in the eastern United States compared to I-, S-, and A-type granites. Formations that were not researched and are highlighted in orange (Figure 11). This is because their size is smaller than 100 km^2 or there not names associated with the formation. These formations were not chosen as they are small and, in many cases, there is not enough information to classify them.

Type of Granite	Average Pluton Area	Total granite formation Count
I-type granite	198 km^2	100
S-type granite	357 km^2	12
A-type granite	401 km^2	9

Table 3: The table displays the total number of I- S-, and A-type granite plutons, and their average size in km^2

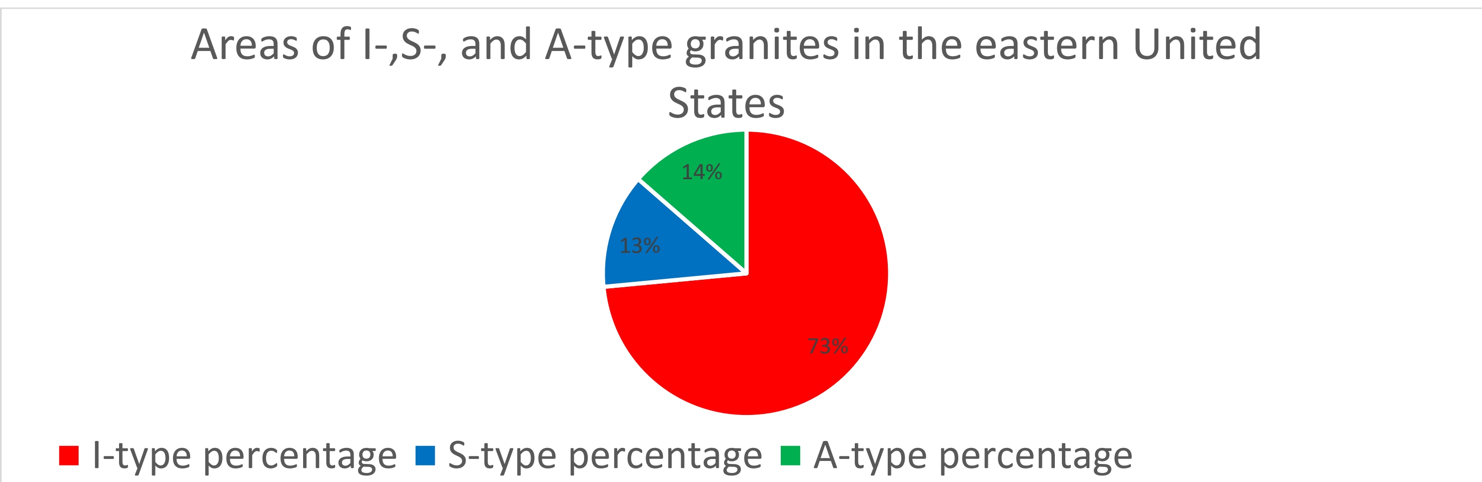

Figure 13: The percentages of I-, S-, and A-type granites displayed in a pie chart

I-type granites have the highest pluton count in the eastern United States whereas S-, and A-type granites have a smaller number of plutons (Table 3). In contrast, the average pluton size is largest for A-, and S-type granites and is smallest for I-type granites. I-type granites are displayed in red and are the most abundant (73%). S- and A-type granites are displayed in blue and green and make up nearly subequal proportions of 13% and 14%, respectively (Figure 13).

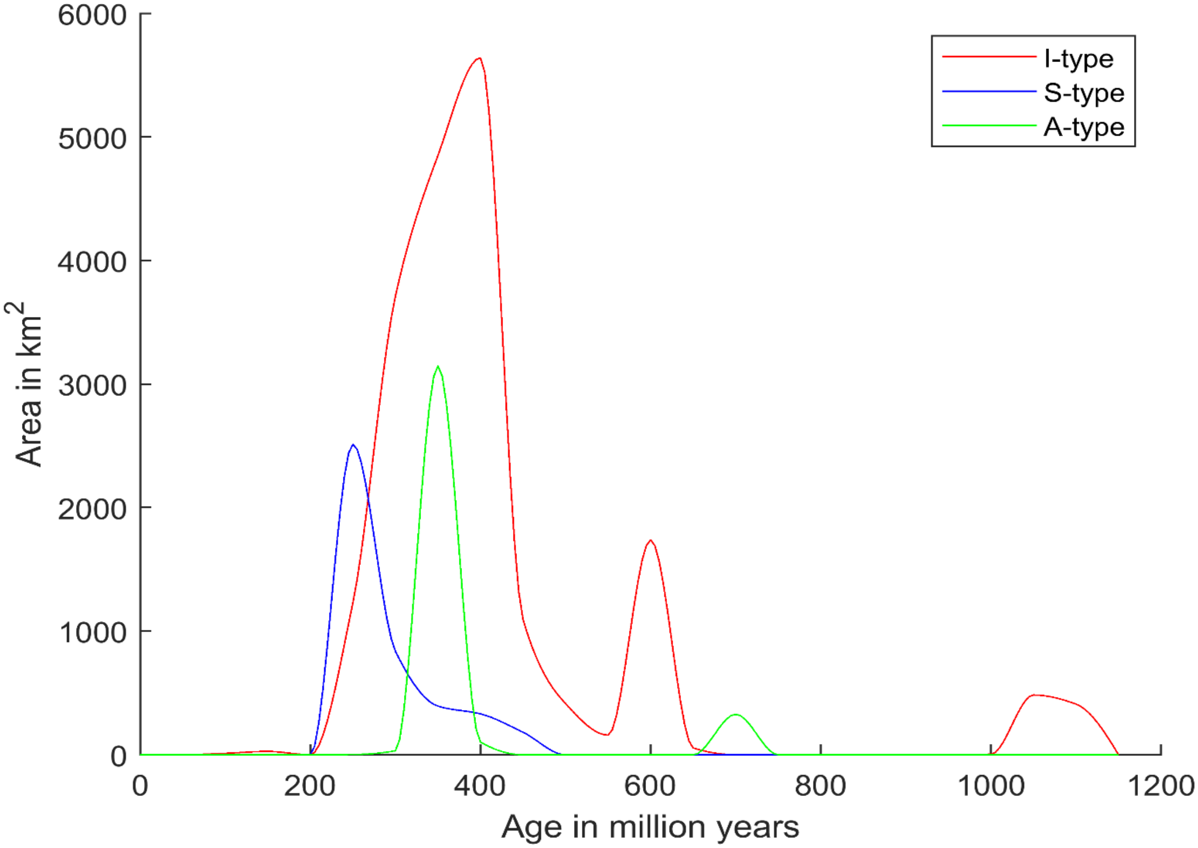

Figure 14: The distribution of ages and area displayed for I-, S- and A-type granites of the eastern United States. The lines plotted in display age in million years vs area of exposure in square kilometers. The granites have been binned in 50 million year groups and the peak at each bin interval corresponds to the total area in that bin.

The peaks in Figure 14 show magmatic fluxes associated with different granite types. Ages have been binned in 50 million-year bins and the peaks display the total area for the given age. I-type granites have the largest magmatic flux which occurs around 400 Ma, whereas S-type granites have the most recent peak occurring around 250 Ma. The most recent event of I-type magmatism is from the White Mountain Petrologic Province. This is difficult to see in Figure 14 given that the exposures area is under $500km^2$. When discussing these areas, it is assumed that area is a first order approximation of volume of magmatism which can be used to estimate magmatic fluxes.

A sequence of F- and t-tests were performed to compare the ages of the various granite types. The two-tailed t-test was used with a standard alpha value of 0.05. Results for comparing I-type granites to S-type granites were calculated to have a t-statistic of 3.07 and a t-critical value of 2.03(Table 4). Results comparing S-type granites to A-type were calculated to have a t-statistic of 1.23 and a t-critical value of 2.17 (Table 5). Results are consistent with the null hypothesis that the proportion of S-type granites relative to A-type granites does not change with respect to time in the eastern United States as the t-critical value for the two-tailed test is greater than the t-statistic. Therefore S-type granites are not younger than A-type granites. In contrast, results are consistent with the alternate hypothesis that the proportion of S-type granites relative to I-type granites does change with respect to time in the eastern United States as the t-critical value for the two-tailed test is less than the t-statistic for these values.

I-vs S-type Granite Statistical Tests

F-test: Two sample	**Variable I-type granite**	**Variable S-type granite**
Mean	438.465	356.4615
Variance	30467.79	5274.603
Observation	100	13
df	99	12
F	5.776319	
F Critical One tail	2.350282	
T-test: Two sample	**Variable 1**	
df	34	
T stat	3.076633	
T Critical two-tail	2.032245	

Table 4: Results for F-tests and two-tailed tests for I-,vs S-type granites

A-types vs S-type Granite Statistical Test

F-test: Two sample	**Variable A-type granite**	**Variable S-type granite**
Mean	414.388	356.461
Variance	16240	5274.6
Observation	9	13
df	8	12
F	3.07904	
F Critical One tail	2.84856	
T-test: Two sample	**Variable 1**	
df	12	

T stat	1.23214	
T Critical two-tail	2.17881	

Table 5: Results of f-tests and t-tests for A- vs S-type granite

I-type vs A-type granite

F-test: Two sample	**Variable I-type granite**	**Variable A-type granite**
Mean	438.465	441.389
Variance	30467.8	16240.7
Observation	100	9
df	99	8
F	1.87601	
F Critical One tail	.170918	
T-test: Two sample	**Variable 1**	
df	11	
T stat	0.524236	
T Critical two-tail	2.20098	

Table 6: Results of f-tests, and t-tests for I- vs A-type granites

One limitation with this study is the uncertainty that lies within the USGS maps. The USGS has analyzed the uncertainty associated with geologic mapping (Richard, et al 1996).The USGS states that there is a scarce number of geologic outcrops and drill hole data and that there is a large amount of interpretation when identifying geologic formations. This is true for much of the formations of the eastern United States that are being classified. These mapping uncertainties describes the inherent uncertainty of the identifying contacts of granite formations in the field, and this has inherent implications in my research. The USGS mapping data has been used extensively throughout this study as the shape and KMZ files used for the creation of the maps and for the identification of formations. There is also uncertainty associated with the ages of the granite formations that are being researched. The default adopted by some states is to report the ages of rocks using a geologic time approach and not an absolute age. In those instances, a literature review was required to find a more restrictive estimate of the age.

Discussion of Results

Many of the granite formations in the USGS database and classified in this study have not been appropriately named making it difficult to find required information for this study. These formations can be seen in the appendix. For example, one geometric form in Maine labelled as “Devonian Granite” has 30 or so plutons that fall under it and include the following formations: “Chandler Lake”, “Monticello”, “Estabrook”, “Whitney Cover”, and many more. Those formations were compiled on the USGS map into a single formation, and the areas could therefore not be calculated. For the purpose of this study I have only considered formations that have an area over 100 km^2 in these regions that fall under these broad terms, unless they have a specific formation name (for example, the Ellicott City granodiorite). This stipulation was added as there are over 4000 plutonic formations identified, many of which are too small to have the information required to classify. For the scope of this study many smaller formations have been disregarded if they were not named units and appropriate petrologic and age information didn’t exist in the literature.

One of the goals of this study was to determine if there was a statistical difference between the ages of I-, S-, and A-type granites. Results are consistent with the null hypothesis that the proportion of S-type granites relative to A-type granites does not change with respect to time in the eastern United States as the t-critical value for the two-tailed test is greater than the t-statistic. Therefore S-type granites are not younger than A-type granites. Results are consistent with the alternate hypothesis that the proportion of S-type granites relative to I-type granites does change with respect to time in the eastern United States as the t-critical value for the two-tailed test is less than the t-statistic for these values. Therefore S-type granites can be said to be younger than I-type granites in the eastern United States with above a 95% certainty. The statistical tests ran on the ages include older formations that fall within the Grenville orogeny and younger formations that fall into the Taconic, Acadian, and Alleghanian orogenies. In this study there are no S-type granites that were found to form from the Grenville time period. There are however several I-type granite formations that fall within the Grenville time period. When these Grenville ages are disregarded for I-type granites there is not a statistical difference in age between S-, and I-type granites in the eastern United States.

Butler and Ragland (1969) discussed intrusions in the piedmont of the Southeastern Appalachian. As part of that work, they report areas of plutons, and therefore comparisons can be drawn between their work and the area determinations made here. These comparisons show the variations in areas and further highlight uncertainties in the mapping methods of plutonic formations. Butler and Ragland (1969) found that the Clouds Creek pluton had an area of 26 km^2 and in this study, the Clouds Creek was found to have an area of 34 km^2. The Winnsboro Pluton has an area of 122 km^2 (Butler and Ragland, 1969) whereas this study found it to have an area of 238 km^2. Liberty Hill Pluton has an area of 363 km^2 (Butler and Ragland, 1969) and has an area of 400 km^2 in this study. Lastly the Pee Dee Pluton has an area of 10 km^2 (Butler and Ragland, 1969) and 10 km^2 in this study. The areas that are used in this study where taken directly from the USGS database. This study relies on the accuracy of the mapping techniques used by the USGS and as shown by comparing the areas calculated with those of another study, some are the same such as the Pee Dee Pluton, whereas others are farther apart such as the Winnsboro Pluton.

The major events that created most of the plutons classified in this study include the Grenville. Taconic, Acadian and Alleghanian orogenies. The Grenville orogeny covers the timespan of roughly 1500-1000 Ma, the Taconic covered roughly 550- 440 Ma, the Acadian covered roughly 416-360 Ma and the Alleghanian covered roughly 352-250 Ma (Murphy and Keppie, 2007). There are a few younger plutons that have ages which occur after these orogenic events. For example, the Ascutney Mountain pluton has an age of 105 Ma and the Conway formation has an age of 185 Ma. These plutons formed from separate melting events that resulted from hotspot activity (Nelson 1995). The Ascutney Mountain and the Conway formation are both a part of the White Mountain Petrologic Province (Nelson 1995). This event was caused by a tectonic plate moving westward over a hotspot in New England resulting in the generation of a batholith at an age younger than the major orogenic events listed above (Nelson 1995).

Comparisons can be made from the findings of this study to those found by Chappell and White (1983). These findings are important as the terminology I-, S-, and A-type granites were most well studied and used for the purpose of differentiating granites in the Lachlan Fold Belt. This study was designed to evaluate the spatial and temporal analysis of granite rocks in the eastern United States in a similar manner done by Chappell and White (1983). It may useful to see how different tectonic settings yield different types of granites. For example, S-type granites occur form tectonic zones that are further inland as there are more sediments being melted farther away from coastal regions. This study found that I-type granites make up 73.5% of the total area of exposed granites in the eastern United States. S-type granites make up around 13%, and A-type granites make up 13.5%. Chappell and White (1983) found I-type granites to make up 52% of the area of the Lachlan Fold Belt. S-type granites make up 47%, and A-type granites make up only 1%. The largest spikes in magmatism in this study can be seen around 400 Ma (Figure 14) which is of Devonian age. The granites that Chappell and White (1983) examined had ages that fell mostly into the Ordovician time period which is around the same time period of the granites that I examined.

Conclusions

A method to classify granites based off the origin of magma is important, as it may give indications to what events took place to form those granites. I-, S-, and A-type granites have been classified in the eastern United States. They have been categorized based off their mineralogy and their area has been displayed in map view in the GIS program ArcMap. Their ages have been approximated from the literature in terms of the geologic age in millions of years (Ma). S-type granites have an age that is younger than I-types granites with 95% certainty. S-type granites do not have an age that is younger than A-type granites with 95% certainty. These results were concluded by running f-tests, and two-tailed tests. This is consistent with the alternate hypothesis that the proportion of S-type granites relative to I-type granites does change in the eastern United States with respect to time. It is consistent with null hypothesis that the proportion of S-type granites relative to A-type granites does not change in the eastern United States with respect to time. I-type granites have the largest area of exposure in the eastern United States compared to S-, and A-type granites taking up 73.5% of the total area. S-type granites have the least amount of coverage taking p 13% with respect to I- and A-type granites. A-type granites take up 14% of the area with respect to I-, and A-type granites. Chappell and White (1984) found in the Lachlan Fold Belt I-type granites taking up 52% of the area studied, S-type granites taking up 47% and A-type granites taking up only 1%. These results differ from those found by Chappell and White in the Lachlan Fold belt mainly because there are not as many S-type granites in the eastern United States as there are in the Lachlan Fold Belt in Australia. The majority of magmatic activity in the eastern United States has taken place during the Acadian orogeny as the largest peak of the ages of granites researched occurs at roughly 400Ma.

Acknowledgements

I would like to thank Austin Gion and Dr. Philip Piccoli for assisting me with this research and helping with any questions that I had during the process. I would like to thank Todd Karwoski for helping set up my power point presentations and the faculty members for their constructive criticism of my presentations and the rough drafts of my thesis as it helped to shape my paper. Lastly, I would like to thank those who worked on ArcGIS, and the various USGS databases as these were both essential in the research of this study.

Bibliography

Aleinikoff J.N., Jahns H.R., Whalsh, J.G., et al. (2013). Bedrock Geologic Map of the Nashua South Quadrangle, Hillsborough County, New Hampshire, and Middlesex County, Massachusetts U.S. Geological Survey, map 3200

Ayuso, A.R., and Arth., G.J., (1992). The Northeast Kingdom batholith, Vermont: magmatic evolution And geochemical constraints on the origin of Acadian granitic rocks. *Contributions to Mineralogy and Petrology*, volume 111, pp. 1-23

Barton, M.D., Battles, D.A., Debout, G.E., Capo, R.C., Christensen, J.N., Davis, S.R., Hanson, R.B., Michelsen, C.J., and Trim, H.E. (1988). Mesozoic contact metamorphism in the western United States. *Metamorphism and crustal evolution of the Western United States*. Prentice-Hall, Inc pp. 111-178

Blackburn, W.H., Metcalf, R.V., and Ragland, P.C., (1994). Geochemical evolution of the Precambrian Old Rag Granite, Virginia, U.S.A. Science direct, volume 111, pp. 177-206.

Butler, J.R., and Raglance., P.C., (1969). A Petrological Survey of Plutonic Intrusions in the Piedmont, Southeastern Appalachians, Contributions to Mineralogy and Petrology, volume 24, pp. 164-190

Chappell, B.W., and White, A.J.R. (1974). Two contrasting granite types. Pacific Geology 8, 173-174

Chappell, B.W. and White, A.J.R. (1983). Granitoid types and their distribution in the Lachlan Fold Belt, Southeastern Australia. Geological Society of America. Geological Society of America Memoirs, 159, 21-34.

Chappell, B.W. and White, A.J.R. (2001). Two contrasting granite types: 25 years later. Australian Journal of Earth Sciences 48, 489-499

Chappell, B., and Simpson, P. (1984). Source Rocks of I- and S-type Granites in the Lachlan Fold Belt, Southeastern Australia [and Discussion]. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences 310 (1514), 693-707

Cleaves, E.T., Edwards, J., and Jr., Glaser, J.D., (1968). Geologic Map of Maryland: Maryland Geological Survey, Baltimore, Maryland, scale 1:250,000

Conrad, D., and D Vanacek., (1990). Industrial Minerals: 200 years and Going Strong: Agency of Natural Resources Department of Environmental Conservation. Geological and Economic Survey Circular C-46, p. 95-102.

Dallmeyer, D.R., and Vanbreeman O., (1981). Rb-Sr whole-rock and $^{40}Ar/^{39}Ar$ mineral ages of the Togus and Hallowell quartz monzonite and Three Mile Pond granodiorite plutons, South-Central Maine: Their bearing on post-Acadian cooling history. Contributions to Petrology and Minerology. Contributions to mineralogy and petrology, volume, 78, pp. 61–73.

Dennis, J.A., and Wright, J.E., (2010). The Carolina terrane in northwestern South Carolina, U.S.A. Late Precambrian-Cambrian deformation and metamorphism in a peri-Gondwanan oceanic arc Advancing Earth and Space Science

Fullagar, D.P., Butler, R.J., Petrochemical and geochronologic studies of plutonic rocks in the southern Appalachians: II, The Sparta granite complex, Georgia. GSA Bulletin

Goldsmith, R., Robinson, P., Wones, D.R., Zartman, R.E., (1991). The Bedrock Geology of Massachusetts. U.S Geological Survey, 1366,
Chapters: E-J

Guthrie, J.O., (1972). The Geology of the northern portion of the Belchertown intrusive complex, West-central Massachusetts. Department of Geology, University of Massachusetts, Master's thesis

Hatcher, D.H., et al (1989). The Appalachian-Ouchitan Orogeny in the United States.
Geological Society of America

Hopson, C.A. (1964). The Crystalline Rocks of Howard and Montgomery County. Maryland Geologic Survey

Horton, et al. (1991). The Geology of the Carolinas. University of Tennessee Press

Hussey, M.A., (1989). Geology of Southwestern Coastal Maine. Maine Geological Survey, Brunswick, Maine 04011

Ingram, S.B. (2012). U-Pb zircon and monazite geochronology and hafnium isotopic geochemistry of neoacadian and early alleghanian plutonic rocks in the Alabama Eastern Blue Ridge, Southern Appalachian Mountains. The University of Alabama, The Department of Geological Science, Master's thesis

Jill, S.S (1992). Mesozoic igneous intrusions in New England and Quebec: Implications from lead (Pb) isotopes on petrogenesis and mantle sources (Ascutney Mountain, Vermont; Mont Saint Hilaire, Quebec; Pliny Complex, New Hampshire). University Microfilms International, The Ohio State University, PhD thesis,

Laurent, R., Pierson. T.C., (1973). Petrology of Alkaline Rocks from Cuttingsville and the Shelburne Peninsula; Vermont. Canadian Journal of Earth Sciences, volume 10, pp. 1244-1256

Loiselle, M.C, and Wones, D. R., (1979). Characteristics and Origin of Anorogenic Granites. Geological Society of America, Abstracts with Programs, volume. 11, pp. 468

Luman, A., and West, D.P., (2001). Norumbega Fault System of the Northern Appalachians. Geological Society of America, volume 331, pp. 378

Maczuga, D.E., (1981). The Petrology and Geochemistry of the Fitchburg plutonic complex, central Massachusetts. Department of Geology and Geography, University of Massachusetts, master's thesis, Martin, J.A., (2019). Five hundred million years of punctuated addition of juvenile crust during extension in the Goochland Terrane, central Appalachian Piedmont Province. International Geology review, volume 62, pp. 523-548

Maryland geologic map data. (2005). Retrieved from https://mrdata.usgs.gov/geology/state/state.php?state=MD.

Murphy, J.B., and Keppie, J.D., (2007). The Acadian Orogeny in the Northern Appalachians. International Geology Review, volume 47, pp. 663-687

Nelson, E. (1995). White Mountain Magma Series. DOI: 10.13140/RG.2.1.1746.0883

Ratcliffe, N.M., (1997). Bedrock Geologic map of the Chester quadrangle, Windsor county, Vermont. U.S Geological Survey

Richard, L.B., Brookshire S.D., Campbell, R.H, Matti, J.C., Soller, D.R., McKee, J.M., Sutter F.G., (1996). Societal Value of Geologic Maps. U.S Geological Survey

Ward, R. (1959). Petrology and Metamorphism of the Wilmington Complex, Delaware, Pennsylvania and Maryland. GSA Bulletin. Vol 70. Issue 11

Sayer, S., (1974). An Integrated Study of the Blue Hills Porphyry and Related United. Massachusetts Institute of Technology. Department of Earth and Planetary science, Master's thesis

Sinha A.K, Hund, E.A., and Hogan, J.P., (1989). Paleozoic Accretionary History Of The North American Plate Margin (Central And Southern Appalachians): Constraints From the Age, Origin, And Distribution Of Granitic Rocks. Department of Geological Sciences, Virginia Polytechnic Institute and State University Blacksburg, Master's thesis

Speer, J.A. , Naeem, A., and Almohandis, A.A., (1989). Small-scale variations and subtle zoning in granitoid plutons: The Liberty Hill Pluton, South Carolina. ScienceDirect, Volume 75, pp. 153-181

Speer, J.A., (1981). Petrology of Cordierite and Almandine Bearing Granitoid Plutons of The Southern Appalachtian Piedmont, U.S.A. The Canadian Mineralogist, volume 19, pp. 35-46

Stewart, B.P., Tucker, D.R., Ayusuo A.R., and Daniel R.L., (2001). Minimum age of the Neoproterozoic Seven Hundred Acre Island Formation and the tectonic setting of the Islesboro Formation, Islesboro block, Maine. Atlantic Geology, volume 37, pp. 41-59

Tollo, P.R., Aleinikoff N.J, Borduas E,A, Paul C. Hackley, C Mark Fanning (2004). Petrologic and geochronologic evolution of the Grenville orogen, northern Blue Ridge Province, Geological Society of America Memoir, volume 197, pp. 78-102

Tomascak, B.P., Brown, M., Solar, G.S., Becker, J.H., and Tian, J., (2004). Source contributions to Devonian granite magmatism near the Laurentian border, New Hampshire and Wester Maine, USA. Science direct, Volume 80, pp. 75-99

Trista, L., (2014) Shenandoah National Park Geologic Resources Inventory Report. U.S. Department of the Interior National Park Service, Natural Resource Stewardship and Science, pp. 747

Virginia Division of Mineral Resources, (1993). Geologic Map of Virginia: Virginia Division of Mineral Resources, scale 1:500,000

Virginia Division of Mineral Resources, (2003). Digital Representation of the 1993 Geologic Map of Virginia, Publication 174, CD ROM (ISO-9660) contains image file, expanded explanation in pdf and ESRI shapefiles, scale 1:500,000

Wenner, D., (1980). Oxygen isotopic compositions of the late orogenic granites in the Southern Piedmont of the Appalachian Mountains, U.S.A., and their relationship to subcrustal structures and lithologies. ScienceDirect, volume 54, pp. 186-199

Wetherill, W.G., (1966). Age measurement in the Maryland Piedmont. American Geophysical Union. Journal of Geophysical Research, volume 71, pp. 2139-2155

Whalen, J.B., Currie, K.L., and Chappell, B.W., (1987). A-type granites: geochemical characteristics, discrimination and petrogenesis. Geological Survey of Canada contribution no. 18886.

Whitney, J.A., (1988). The origin of granite. The role of source of water in the evolution of granitic magmas. Geological Society of America Bulletin, volume100, pp. 1886-1897

Whitney, J.A., Jones, L.M., and Walker, R,L., (1976). Age and origin of Stone Mountain Granite, Lithonia district Georgia. Geological Society of America Bulletin, volume 87, pp. 367

Wilson R.J., (2001). U/Pb Zircon Ages of Plutons from the Central Appalachians and GIS-Based assessment of Plutons with Comments on Their Regional Tectonic Significance. Virginia Polytechnic Institute, master's thesis

Winchester, L.C., (1997). Alleghenian Plutonism In the Eastern Blue Ridge Province of The Southern Appalachians: Origin and Tectonic Setting. University of North Carolina, master's thesis

Winter, J.D., (2009). Principles of Igneous and Metamorphic Petrology. Pearson.

Honor Code

I pledge on my honor that I have not Given or received any unauthorized assistance on This assignment/examination. Ian Harper

Appendix

The following table displays the granite formations that have been researched and classified. The ages are listed under their designated classification I-, S-, and A-type granites. The Age reference displays where the ages were taken from the full references of theses ages are listed in the bibliography. The indicator section includes either the mineral that was used to classify the granite, or if the formation was cited directly as being an I-,S-, or A-type the authors last name and date is listed.

	Age (Ma)							
Unit name	**I-type**	**S-type**	**A-type**	**Unknown**	**Area km^2**	**State**	**Age Reference**	**Indicator**
Almond Trondhjemite				343	36.695	AL	Stanton 2012	
Andover Granite		446			331.251	MA	Goldsmith et al. 1991	(Goldsmith 1991)
Arden Granite	396				11.419	DE	Ward 1959	Hornblende
Ascutney Mountain stock – granite	105.5				2.841	VT	Schneiderman 1991	Hornblende
Averill pluton	388.5				257.315	VT	USGS	Hornblende
Ayer Granite - Devens-Long Pond facies				433	44.899	MA	Robinson 1987	
Ayer Granite, Clinton facies				433	44.174	MA	Robinson 1987	
Ayer Granodiorite				407	18.527	NH	Walsh 2013	
Barber Hill stock - syenite				114	0.075	VT	USGS	
Barnard Gneiss proper (of Richardson, 1924)				469	32.154	VT	Ratcliffe 1997	
Bear Island Granodiorite				469	0.492	VA	USGS description	
Beech Granite	613				263.016	TN	USGS description	Hornblende
Belchertown Complex	388.5				80.842	MA	Guthrie 1972	Hornblende
Bethlehem Granodiorite				435	904.884	NH	USGS	
Blue Hill Granite Porphyry			437		5.927	MA	Wones 1987	Riebeckite
Bluff Springs Granite		363			119.446	AL	Ingram 2012	Primary muscovite
Braintree Intrusive Complex - metadiorite to metamonzodiorite	419				2.248	VT	USGS description	Hornblende

Buffalo Granite	602				292.090	VA	USGS description	Hornblende	
Buggs Island Pluton				314	226.614	VA	USGS description		
Burkeville Pluton				250	178.927	VA	USGS description		
Cape Ann Complex	426				213.124	MA	Goldsmith et al. 1991	Hornblende	
Carysbrook Pluton				457	110.823	VA	Wilson 2001		
Chelmsford Granite				375	47.704	MA	Walsh 2013		
Cherry Hill Granite	388				4.237	MC	USGS description	Hornblende	
Cherryville Granite				340	231.741	VA	USGS description		
Columbia Pluton				454	53.840	VA	USGS description		
Concord Granite	410				2097.201	NH	USGS description	Hornblende	
Conway Granite				185	883.288	NH	USGS description		
Cooleyville Granitic Gneiss	385				25.044	MA	USGS description	Hornblende	
Crozet Granite	1046				4.559	VA	USGS description	Hornblende	
Dale City Quartz Monzonite				560	0.178	VA	USGS description		
Dalecarlia Instrusive Suite				492	0.332	VA	USGS description		
Dedham Granite				607	729.315	MA	Goldsmith et al. 1991		
Derby pluton - granodiorite and tonalite				370	39.700	VT	Ayuso, Arth 1992		
Diorite-gabbro - Clouds Creek pluton		313			8.231	SC	Speer 1981	Cordierite	
Dioritic phase [of Preston Gabbro]	460				9.825	CT	USGS	Hornblende	

							description	
Elk Park Plutonic Group - Biotite quartz monzonite	1050				480.226	VA	USGS description	Hornblende magnetite
Ellicott City Granodiorite	458				12.055	MD	Sinha 1989	Hornblende
Ellisville Biotite Granodiorite	452				201.160	VA	USGS description	Hornblende
Falls Church Intrusive Suite	492				21.117	VA	USGS description	Hornblende
Falls Run Granite Gneiss	410				25.097	VA	USGS description	Hornblende
Falmouth Intrusive Suite	312				63.977	VA	USGS description	Hornblende
Fine Creek Mills Granite				629	10.115	VA	USGS description	
Fitchburg Complex		470			182.631	MA	Maczuga 1981	(Maczuga 1981)
Flat Rock Granite				1034	2.965	VA	USGS description	
Georgetown Intrusive Suite	513				23.481	VA	USGS description	Hornblende
Goldvein Pluton				492	84.041	VA	USGS	
Granite - Liberty Hill pluton		295			399.577	SC	Speer 1989	Cordierite
Granite of Rattlesnake Hill pluton			388		16.745	MA	Wones 1987	Riebeckite
Granite of the Fall River pluton				600	300.574	MA	Goldsmith et al. 1991	
Granodiorite of the Indian Head pluton	402				28.950	MA	Goldsmith et al. 1991	Hornblende
Green Springs Pluton - Quartz diorite and granite.				311	51.569	VA	USGS	
Guilford Quartz Monzonite	420				9.977	MD	Hopson 1964	Hornblende
Gunpowder Granite	550				12.798	MD	Hopson 1964	Hornblende
Hissop Granite				396	52.627	AL	USGS description	
Kowaliga Gneiss				460	319.737	AL	USGS description	
Lahore Complex - Amphibole	469				19.771	VA	USGS	Hornblende

monzonite							description	
Leatherwood Granite	516				260.162	VA	USGS description	Hornblende
Lebanon Gabbro	388				36.367	CT	USGS description	Hornblende
Little Ascutney stock - gabbro and diorite	105				7.805	VT	USGS description	Hornblende
Lost Nation granite	442				98.931	NH	USGS description	Hornblende
Maidstone pluton	388				108.935	NH	USGS description	Hornblende
Melrose Granite	515				100.258	VA	USGS description	Hornblende
Middlefield Granite	447				7.812	MA	USGS description	Hornblende
Mobley Mountain Granite	652				6.658	VA	USGS description	Hornblende
Monadnock Mountain pluton - essexite	175				0.614	VT	USGS description	Hornblende
Montpelier Metanorthosite	1050				3.777	VA	USGS description	Hornblende
Mount Osceola Granite, Green biotite mesoperthitic granite	186				21.887	NH	Moench 1989	Hornblende
Nahant Gabbro and gabbro at Salem Neck	484				2.597	MA	USGS description	Hornblende
Narragansett Pier Granite			275		2.067	CT	USGS description	Cheney 1993
Newark pluton	388				37.203	VT	USGS description	Hornblende
Newberry granite				442	408.797	SC	USGS description	
Newburyport Complex				455	24.906	MA	USGS description	
North View Granite			314		32.714	VA	USGS	

							description	
Occoquan Granite				494	150.798	VA	USGS description	
Old Rag Granite				1115	31.013	VA	USGS description	
Opelika Complex; Bottle Granite				480	115.584	AL	USGS description	
Partridge Formation (includes Brimfield Schist of Emerson, 1917)	460				0.381	MA	Goldsmith et al. 1991	Hornblende
Peabody Granite	395				46.541	MA	USGS description	Hornblende
Petersburg Granite	330				845.575	VA	USGS description	Hornblende
Pinewood Adamellite				291	3.043	CT	USGS description	
Port Deposit Granodiorite	412				7.539	DE	Sinha 1989	Hornblende
Potter Hill Granite Gneiss plus Narragansett Pier Granite		270			6.572	CT	USGS description	Murray 2003
Prescott Complex	388				5.275	MA	Guthrie 1972	Hornblende
Preston Gabbro	460				28.481	CT	USGS description	Hornblende
Quincy Granite			437		97.588	MA	Sayer 1974	Riebeckite
Red Oak Pluton				621	104.042	VA	USGS description	
Relay Quartz Diorite	550				7.533	MD	Hopson 1964	Hornblende
Robertson River Igneous Suite - Amissville alkali feldspar granite			724		327.823	VA	USGS description	Riebeckite
Rockfish River Pluton				573	21.721	VA	Ingram 2012	
Rockford Granite		376			101.432	AL	Ingram 2012	Cordierite
Schaeffer Hollow Granite				1050	1.824	VA	USGS description	
Scituate Igneous Suite - alkali-feldspar granite			373		97.053	RI	USGS description	Riebeckite/aegerine
Scituate Igneous Suite - diorite/gabbro	388				2.726	RI	USGS	Hornblende

							description	
Sharpners Pond Diorite	430				175.561	MA	Goldsmith et al. 1991	Hornblende
Shelton Formation				442	139.072	VA	USGS description	
Somerset Reservoir Granite - aplitic to pegmatitic granite				965	4.483	VT	USGS description	
Spaulding Tonalite	410				853.922	NH	USGS description	Hornblende
Stamford Granite - aplitic granite				962	53.120	VT	USGS description	
Uchee Complex; Hospilika Granite				900	1.237	AL	USGS description	
Waterford Group plus Stony Creek Granite Gneiss plus Narragansett Pier	270				19.712	CT	USGS description	Hornblende
Wenham Monzonite	395				12.197	MA	USGS description	Hornblende
Westerly Granite	276				1.736	CT	USGS description	Hornblende
Williamsburg Granodiorite	373				6.552	MA	USGS description	Hornblende
Woodstock Quartz Monznoite	444				2.537	MD	Sinha 1989	Hornblende
Zana Granite	460				130.799	AL	Stanton 2012	Hornblende
Granite - Clouds Creek pluton		315			24.635	SC	Sinha 1997	Cordierite
Granite - Cuffytown Creek pluton		294			16.707	SC	Sinha 1997	Sillimanite/peraluminous
alkali-feldspar granite of Cumberland			388.5		3.670	SC	USGS description	Aegerine/Riebeckite
Baltimore Gabbro Complex	1100				410.502	MD	Wetherill 1966	Hornblende
Buckingham Complex - Quarz diorite	305				2.903	VA	USGS description	Hornblende
Cuttingsville stock - essexite	101				0.354	VT	USGS description	Hornblende
Cuttingsville stock - quartz syenite	101				0.917	VT	USGS description	Hornblende

Diorite at Goff ledges	460				3.436	MA	USGS description	Hornblende
Dioritic phase [of Preston Gabbro]	460				9.825	CT	USGS description	Hornblende
East Barre plutons				380	8.336	VT	USGS description	
East Bethel plutons				380	0.722	VT	USGS description	
Echo Pond pluton - granodiorite and granite				375	2.499	VT	Sinha 1997	
Equigranular granite of Lowrys pluton	385				52.440	SC	USGS description	Hornblende
Esmond Granite				621	3.070	MA	USGS description	
Esmond Igneous Suite - fine-grained granite				621	6.972	RI	USGS description	
Exeter Diorite	406				149.622	NH	USGS description	Hornblende
Fairlee Quartz Monzonite				410	10.980	NH	USGS description	
French pond granite				365	1.242	NH	USGS description	
Gabbro - Abbeville pluton				380	5.265	SC	USGS description	
Granite and trondhjemite dikes of Chester and Athens domes				392	5.375	VT	USGS description	
Granite of Salisbury Plutonic Suite				385	227.289	NC	USGS description	
Granites of southeastern Rhode Island - granite	630				73.495	RI	USGS description	Hornblende
Hastingsite granite	187				5.111	NH	USGS description	Hornblende
Hammett Grove Meta-igneous Suite - ultramafic rocks	390				3.867	SC	USGS description	Hornblende

Hope Valley Alaskite Gneiss				601	100.940	MA	USGS description	
Kinsman Granodiorite				400	2195.318	NH	USGS description	
Knox Mountain pluton		377			173.283	VT	USGS description	
Mafic phase [of Narragansett Pier Granite]	260			650	3.150	CT	USGS description	Hornblende
Max Patch Granite				541	79.739	NC	USGS description	
Milford granite				630	93.557	MA	USGS description	
Mount Rogers Group including Bakersville Gabbro	600				11.324	TN	USGS description	Hornblende
Nonewaug Granite				380	81.359	CT	USGS description	
Norbeck Quartz Diorite	510				30.323	MD	Hopson 1964	Hornblende
Nulhegan pluton - inner zone	390				97.565	VT	USGS description	Hornblende
Oliverian Plutonic Suite - biotite granite	460			690	22.727	NH	USGS description	Hornblende
Pacolet granite				380	106.316	SC	USGS description	
Pee Dee Gabbro				314	10.095	NC	USGS description	
Pegmatite - Amelia pegmatite district				261	1.094	VA	USGS description	
Pegmatite - Goochland pegmatite district				550	0.388	VA	USGS description	
Ponaganset Gneiss	557				96.030	MA	USGS description	Hornblende
Rawsonville trondhjemite gneiss - aplite				680	7.204	VT	USGS description	
Roseland Anorthosite				1045	30.828	VA	USGS	

							description	
Stiles Pond pluton				360	0.221	VT	USGS description	
Straw Hollow Diorite and Assabet Quartz Diorite undifferentiated	430				20.441	MA	USGS description	Hornblende
Striped Rock Granite	695				49.259	VA	USGS description	Hornblende
Topsfield Granodiorite	640				48.860	MA	USGS description	Hornblende
Two-mica granite of northern and southeastern New Hampshire				325	231.959	NH	USGS description	
Victory pluton	360				81.935	VT	USGS description	Hornblende
West Charleston pluton				375	2.444	VT	Sinha 1989	
Westwood Granite				579	60.358	MA	USGS description	
Willoughby pluton - inner zone				376	1.555	VT	USGS description	
Winnipesaukee Tonalite	392				657.878	NH	USGS description	Hornblende
Gabbro - Calhoun Falls pluton				380	34.266	SC	USGS description	
Granite - Bald Rock pluton	323				494.961	SC	USGS description	Hornblende
Granite - Batesburg (gneissic) pluton				291	155.181	SC	Hatcher 1989	
Granite - Catawba-Roddey pluton				323	13.283	SC	Winchester 1997	
Granite - Cherryville pluton				375	26.267	SC	Horton 1991	
Granite - Clover pluton				322	39.779	SC	Horton 1991	
Granite - Cold Point pluton				320	14.756	SC	Horton 1991	
Granite - Coronaca pluton				278	43.836	SC	West 1998	
Granite - Edgefield pluton				280	12.895	SC	Sinha 1997	
Granite - Harbison pluton				309	12.358	Sc	Horton 1991	
Granite - Pageland pluton	296				42.271	SC	Winchester 1997	Hornblende
Granite - Winnsboro pluton	301				238.004	SC	Winchester 1997	Hornblende

Granite - York pluton				322	49.828	SC	Winchester 1997	
Gabbro - Mt. Carmel pluton				358	22.687	SC	Sinha 1997	
Gabbro - Mecklenburg pluton				444	1.683	SC	Dennis 1997	
Gabbro - Greenwood pluton				399	15.212	SC	Dennis 1997	
Gabbro - McCormick pluton				399	9.130	SC	Dennis 1997	
Diorite-gabbro - Dutchman's Creek pluton	579				43.013	SC	USGS description	Hornblende
Gabbro - Buffalo pluton				383	18.761	SC	Dennis 1997	
Gabbro - Chester pluton				400	4.421	SC	USGS description	
Gabbro - North York pluton				322	0.526	SC	Winchester 1997	
Gabbro - Odgen pluton	399				66.381	SC	Hatcher 1989	Hornblende
Gabbro - Rock Hill North pluton				479	18.611	SC	Horton 1991	
Gabbro of Concord Plutonic Suite	450				282.722	NH	Dennis 1997	Hornblende
Newport Intrusive Complex - granodiorite				425	22.911	VT	USGS description	
Black Mountain pluton of the Guilford dome				364	5.535	VT	USGS description	
Diorite at Rowley	460				6.096	MA	USGS description	Hornblende
Grant Mills Granodiorite				377	0.280	MA	Horton 1991	
Sebago Pluton/Batholith		298			2089.034	ME	USGS description	Metling from metasediments
Monticello	380				592.426	ME	USGS description	Hornblende
Passadumkeag River pluton	379				517.972	ME	USGS description	Hornblende
Roseville, Wise and Lemon Springs Intrusives				310	1656.336	NC	USGS description	
Churchland Plutonic Suite (Western group) - Churchland	282				303.912	NC	USGS description	
Milford Dedham granite				607	107.088	MA	USGS description	
Hartland Pluton	380				200.082	ME	USGS	Hornblende

							description	
Islesboro Formation	646				453.181	ME	Sinha 1989	Hornblende
Deblois pluton	393				1330.221	ME	USGS description	Hornblende
Chandler lake and others			393		3029.395	ME	USGS description	Loiselle 1989
Katahdin	400				1352.211	Me	USGS description	Hornblende
Attean pluton	443				458.159	ME	USGS description	Hornblende
Whitney Cove	496				344.332	ME	Ayuso, Arth 1992	Hornblende
Songo pluton	382				325.659	ME	USGS description	Hornblende
Lexington				404	230.875	ME	USGS description	
Kittery Formation of Merrimack Group				473	127.572	Me	Hussey 1989	
Moxie	400				135.842	ME	USGS description	Hornblende
Redington				408	136.610	ME	Tomascak 2004	
Lyman pluton				322	116.738	ME	USGS description	
Umbagog pluton	384				140.480	ME	USGS description	Hornblende
Red Beach	380				148.190	ME	USGS description	Hornblende
Sugarloaf				389	202.706	ME		
Biddeford pluton				300	116.738	ME	Hussey 1989	
Plumbago				380	114.156	ME	Goldsmith et al. 1991	
High Shoals Granite.	317				1656.336	NC	Goldsmith et al. 1991	Hornblende
Chapel Hill				633	1353.178	NC	USGS description	

Lilesville granite.				326	303.912	NC	USGS description	
Mooresville				390	190.916	NC	USGS description	
oliverian suite				474	248.557	NC	Walsh 2013	
Mascoma Granite				450	357.910	NH	USGS description	
Owls Head dome intrusive rocks				444	208.501	NH	USGS description	
Keene and Surry dome intrusive rocks				444	434.611	NH	USGS description	
Long Mountain pluton				350	129.166	NH	USGS description	
Finger Lakes	325				409.449	NY	USGS description	Hornblende
Hudson Mohawk	612				390.568	NY	USGS description	Hornblende
Adirondack	612				205.959	NY	USGS description	Hornblende
Elberton Granite		325			805.276	GA	Wenner 1981	Wenner 1981
Odessa Granite				340	525.684	GA	USGS description	
Sparta Granite Complex				295	498.352	GA	Fullagar 1976	
Siloam Granite				269	265.108	GA	USGS description	
Ben Hill Granite				325	150.456	GA	USGS description	
Palmetto Granite				330	150.349	GA	USGS description	
Rhode Island Batholith	276				859.035	MA	USGS description	Hornblende
Milford Granite				630	156.860	MA	USGS description	
New Bedford Granite				600	144.908	MA	USGS	

							description	